

**Enhanced soil quality with reduced tillage and solid manures in organic farming – a synthesis of 15
years**

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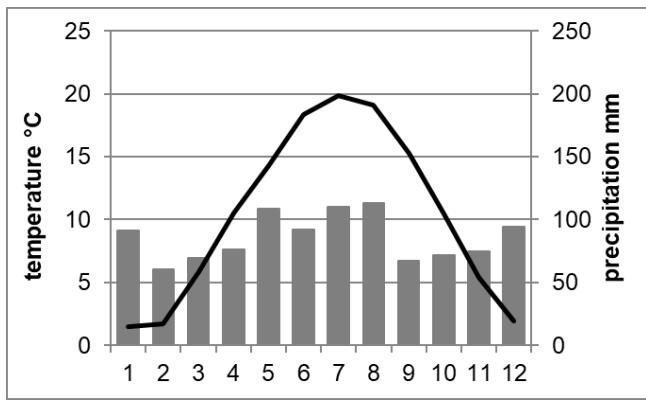


Figure S1. Average monthly precipitation (mm, bars) and temperature (°C, line) in 2003-2018 in Frick.

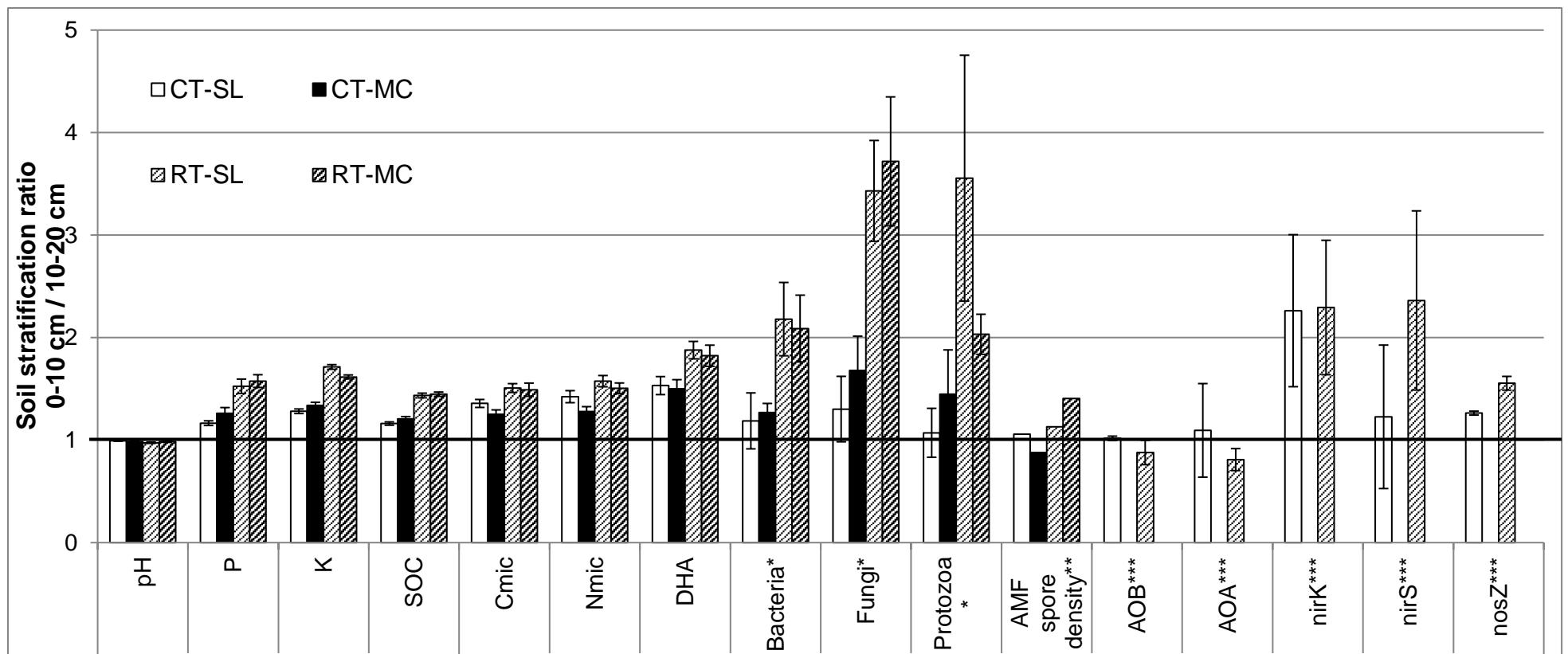


Figure S2. Soil stratification ratio between the 0-10 and 10-20 cm soil layer of soil chemical and biological indicators. Tillage factors are ploughing (CT) and reduced tillage (RT). Fertilisation includes a slurry system (SL) and a system with manure compost and slurry (MC). Soil biochemical data were sampled in 2018. Those data were pooled for biodynamic preparations ($n = 8$). *Abundance of bacteria, fungi and protozoa derive from PLFA analysis ($n=4$) from Kuntz et al. (2013), **arbuscular mycorrhizal (AMF) spore densities ($n=4$) from Säle et al. (2015) and ***nitrifiers and denitrifier rRNA data ($n=3$) from Krauss et al. (2017) include only data from plots without biodynamic preparations.

Table S1. Chemical and biological soil parameters sampled in 2018 in the 0-10 cm and 10-20 cm soil layer. Means (standard deviation) are displayed. Treatment differences were tested with a linear mixed effect model (F-values and levels of significance, (*) $p<0.1$, * $p<0.05$, ** $p>0.01$, *** $p>0.001$). P – phosphorous, K – potassium, Mg – magnesium, SOC – soil organic carbon, Cmic/Nmic – microbial biomass C and N, DHA – dehydrogenase activity. CT – ploughing, RT – reduced tillage, SL – slurry, MC – manure compost/slurry.

Till.	Fert.	Prep.	0-10 cm								10-20 cm								
			pH	P	K	Mg	SOC	Cmic	Nmic	DHA ($\mu\text{g g}^{-1}$ DM d $^{-1}$)	pH	P	K	Mg	SOC	Cmic	Nmic	DHA ($\mu\text{g g}^{-1}$ DM d $^{-1}$)	
			(H ₂ O)	(mg kg $^{-1}$ DM)			(%)	(mg kg $^{-1}$ DM)			(H ₂ O)	(mg kg $^{-1}$ DM)			(%)	(mg kg $^{-1}$ DM)			(%)
CT	MC	without	7.27	118.6	605.9	1495.7	2.37	1097.9	155.7	367.6	7.36	100.0	454.3	1543.8	1.98	840.8	119.2	238.9	
			(0.27)	(25.6)	(23.4)	(727.2)	(0.44)	(80.9)	(15.2)	(36.8)	(0.22)	(35.2)	(31.3)	(792.0)	(0.30)	(105.5)	(16.8)	(58.9)	
CT	MC	with	7.25	108.7	601.6	1740.0	2.42	966.2	136.2	325.0	7.37	86.3	449.0	1784.8	1.97	813.8	110.9	234.5	
			(0.29)	(28.8)	(45.6)	(1045.0)	(0.39)	(127.7)	(13.8)	(87.2)	(0.16)	(28.1)	(33.7)	(1031.1)	(0.26)	(88.3)	(17.8)	(73.0)	
CT	SL	without	7.38	116.4	559.9	1912.4	2.26	1148.0	165.6	354.0	7.45	99.6	427.2	1936.2	1.98	820.3	112.7	251.0	
			(0.20)	(6.0)	(48.1)	(908.5)	(0.29)	(4.7)	(3.9)	(28.2)	(0.17)	(10.8)	(41.0)	(882.9)	(0.25)	(49.3)	(12.8)	(35.2)	
CT	SL	with	7.32	106.9	522.8	1697.6	2.33	1099.8	156.3	373.8	7.35	92.8	418.2	1698.8	1.97	839.0	114.1	236.5	
			(0.27)	(21.3)	(33.6)	(762.8)	(0.37)	(102.9)	(25.7)	(56.7)	(0.21)	(19.3)	(23.6)	(829.0)	(0.28)	(45.7)	(7.8)	(66.2)	
RT	MC	without	7.26	158.3	722.6	1359.2	3.04	1401.3	204.9	498.5	7.29	103.4	441.0	1407.8	2.14	1006.8	143.3	284.9	
			(0.20)	(17.1)	(38.6)	(603.1)	(0.38)	(76.2)	(10.7)	(58.2)	(0.16)	(22.3)	(32.5)	(728.6)	(0.33)	(109.4)	(15.3)	(33.9)	
RT	MC	with	7.18	147.7	712.4	1446.4	2.99	1447.7	207.7	452.6	7.36	93.6	447.8	1571.0	2.04	918.5	132.1	248.7	
			(0.26)	(19.0)	(52.9)	(749.9)	(0.38)	(186.5)	(35.1)	(94.8)	(0.29)	(15.6)	(34.2)	(928.7)	(0.32)	(109.6)	(19.4)	(69.9)	
RT	SL	without	7.18	136.5	655.0	1802.1	2.90	1501.7	214.5	458.2	7.40	89.4	374.7	1845.5	1.98	970.2	134.9	259.9	
			(0.29)	(10.0)	(22.4)	(846.5)	(0.29)	(202.8)	(31.4)	(37.0)	(0.16)	(12.7)	(20.5)	(874.7)	(0.20)	(87.6)	(17.0)	(38.1)	
RT	SL	with	7.24	134.4	649.5	1699.1	2.75	1328.9	191.3	488.5	7.40	91.6	387.1	1694.7	1.97	906.8	123.6	251.4	
			(0.25)	(18.1)	(50.1)	(870.1)	(0.26)	(121.5)	(24.8)	(52.5)	(0.31)	(23.6)	(23.9)	(872.0)	(0.29)	(80.0)	(18.5)	(44.9)	
ANOVA																			
Tillage (T)			12.77*	24.89*	104.71**	1.73 ns	97.22**	61.57**	74.64**	58.74**	0.24 ns	0.00 ns	5.37 ns	0.84 ns	1.21 ns	25.57*	20.06*	1.35 ns	
Fertilisation (F)			2.80 ns	2.38 ns	33.79**	13.47*	7.23*	1.53 ns	1.40 ns	0.24 ns	1.86 ns	0.08 ns	19.05**	11.56*	1.17 ns	0.20 ns	2.05 ns	0.05 ns	
Biodyn. Prep. (P)			1.16 ns	8.51*	1.91 ns	0.00 ns	0.95 ns	5.25*	6.32*	0.60 ns	0.01 ns	3.22(*)	0.03 ns	0.00 ns	2.76 ns	6.86*	8.35*	2.82 ns	
T x F			3.90(*)	1.52 ns	0.02 ns	1.22 ns	0.85 ns	2.28 ns	3.54 ns	0.40 ns	0.27 ns	0.42 ns	2.67 ns	1.00 ns	1.33 ns	0.30 ns	0.95 ns	0.92 ns	
T x P			0.46 ns	0.39 ns	0.39 ns	0.04 ns	12.23*	0.16 ns	0.18 ns	0.02 ns	0.68 ns	0.68 ns	1.15 ns	0.00 ns	1.57 ns	5.51*	2.33 ns	0.47 ns	
F x P			1.05 ns	0.66 ns	0.46 ns	7.70*	0.71 ns	1.03 ns	0.65 ns	7.88*	1.19 ns	1.43 ns	0.00 ns	11.72**	1.69 ns	1.34 ns	0.86 ns	0.22 ns	

Table S2. Marketable yields of three crop rotation periods in the Frick trial between 2003 and 2018. Mean yields (standard deviation) are displayed in t dry matter ha⁻¹ and include grain yields for winter wheat (WW), sunflower (SF) and spelt (SP) and total biomass yields for grass-clover (GC) and silage maize (SM). *In 2010, only sunflower biomass yields can be given due to slug invasion. Treatment differences were tested with an ANOVA (F-values and levels of significance, (*)p<0.1, *p<0.05, **p>0.01, ***p>0.001). CT – ploughing, RT – reduced tillage, SL – slurry, MC – manure compost/slurry.

year	crop	1st rotation					2nd rotation					3rd rotation						
		2003 WW	2004 SF	2005 SP	2006 GC	2007 GC	2008 SM	2009 WW	2010 SF*	2011 SP	2012 GC	2013 GC	2014 WW	2015 SM	2016 SP	2017 GC	2018 GC	
Till.	Fert.	Prep.																
CT	MC	without	4.46 (0.68)	3.04 (0.27)	2.34 (0.53)	6.85 (0.89)	7.28 (0.76)	11.31 (1.14)	3.33 (0.31)	9.35 (0.95)	2.31 (0.18)	8.72 (0.69)	11.27 (1.4)	4.32 (0.37)	10.57 (2.56)	1.23 (0.19)	10.86 (1.04)	9.21 (1.73)
CT	MC	with	4.13 (1.51)	3.01 (0.51)	2.46 (0.55)	6.48 (0.52)	7.65 (0.92)	12.29 (1.03)	3.26 (0.25)	8.55 (1.06)	2.30 (0.17)	8.44 (0.87)	12.28 (0.96)	4.45 (0.28)	10.24 (1.06)	1.45 (0.13)	9.41 (1.13)	8.73 (1.06)
CT	SL	without	5.50 (0.23)	3.35 (0.21)	2.55 (0.11)	8.26 (0.69)	8.65 (0.63)	12.64 (1.19)	3.55 (0.2)	8.04 (0.15)	2.17 (0.19)	8.59 (0.59)	11.67 (0.71)	4.49 (0.24)	11.16 (1.59)	1.28 (0.28)	10.46 (1.56)	9.19 (2.06)
CT	SL	with	4.84 (1.18)	3.15 (0.2)	2.15 (0.31)	8.45 (0.53)	7.60 (1.56)	12.83 (0.4)	3.53 (0.31)	8.82 (0.58)	2.29 (0.45)	8.55 (0.65)	11.92 (1.19)	4.40 (0.38)	10.63 (1.42)	1.27 (0.26)	11.04 (1.21)	9.44 (2.75)
RT	MC	without	3.58 (1.19)	3.17 (0.39)	2.22 (0.52)	9.34 (0.8)	9.99 (0.86)	17.10 (0.87)	4.03 (0.24)	6.30 (0.89)	1.98 (0.28)	8.40 (0.79)	10.34 (0.5)	4.23 (0.45)	9.21 (0.67)	1.18 (0.58)	10.66 (1.21)	8.38 (0.93)
RT	MC	with	3.57 (1.18)	2.89 (0.64)	2.28 (0.72)	9.03 (0.46)	10.05 (0.62)	16.57 (1.08)	4.20 (0.25)	7.36 (1.18)	2.15 (0.31)	8.01 (0.67)	10.54 (0.92)	4.08 (0.48)	9.72 (0.6)	1.07 (0.52)	10.59 (1.78)	8.53 (1.90)
RT	SL	without	4.78 (0.2)	3.30 (0.2)	2.24 (0.4)	10.10 (0.81)	9.07 (1)	16.95 (1.04)	4.20 (0.08)	6.77 (0.64)	2.05 (0.21)	8.12 (0.38)	11.17 (0.48)	4.62 (0.14)	9.62 (0.64)	1.04 (0.17)	10.43 (0.90)	8.20 (1.00)
RT	SL	with	4.47 (0.43)	3.22 (0.26)	1.98 (0.33)	10.15 (0.27)	9.29 (2.1)	15.31 (1.52)	4.27 (0.14)	7.44 (0.86)	1.94 (0.14)	8.39 (0.74)	11.32 (0.61)	4.29 (0.28)	8.99 (0.94)	1.25 (0.42)	10.89 (1.21)	8.63 (1.29)
ANOVA																		
Tillage (T)		6.93†	0.01ns	1.25ns	70.3**	32.1*	94.4**	120.2**	17.5*	5.40ns	0.98ns	10.3*	0.58ns	4.85ns	0.81ns	0.73ns	1.67ns	
Fertilisation (F)		15.9**	4.31†	0.32ns	63.5***	0.08ns	0.07ns	7.56*	0.23ns	0.92ns	0.005ns	1.95ns	1.46ns	0.08ns	0.05ns	1.92ns	0.08ns	
Biodyn. Preparations (P)		3.87†	4.27ns	2.35ns	0.45ns	0.11ns	0.68ns	0.37ns	2.92ns	0.42ns	0.62ns	2.61ns	2.38ns	0.52ns	1.15ns	0.28ns	0.04ns	
T x F		0.14ns	0.0004ns	0.06ns	5.14†	5.49†	3.58ns	0.85ns	2.51ns	0.0004ns	0.02ns	1.77ns	0.69ns	0.32ns	0.20ns	1.54ns	0.12ns	
T x P		1.02ns	0.21ns	0.08ns	0.02ns	0.56ns	7.53*	1.44ns	3.02ns	0.04ns	0.12ns	0.84ns	3.14ns	0.3ns	0.11ns	1.80ns	0.21ns	
F x P		0.93ns	0.01ns	7.21*	1.96ns	0.96ns	2.42ns	0.04ns	1.40ns	0.40ns	2.47ns	0.65ns	2.00ns	0.94ns	0.12ns	7.34*	0.33ns	